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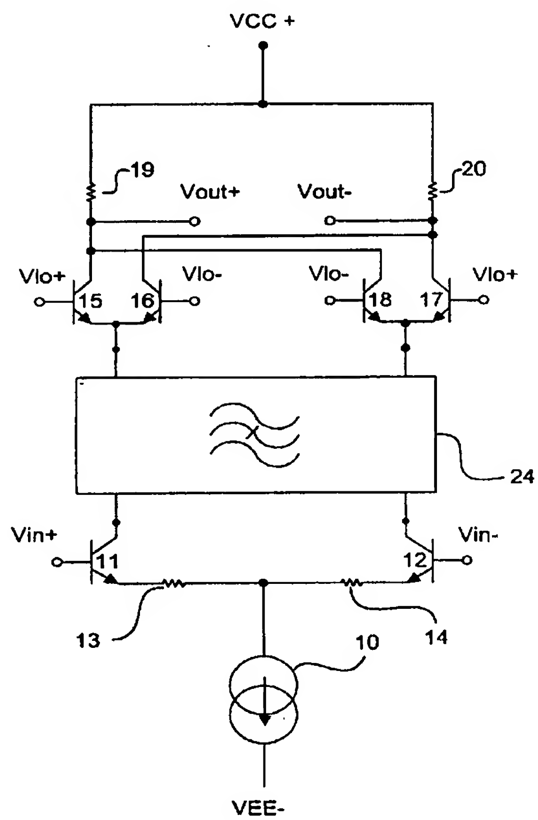
(54) **MIXEUR ARBORESCENT A FILTRE INTERETAGE**
(54) **TREE MIXER WITH INTERSTAGE FILTER**



(57) Les mixeurs arborescents courants comportent une étage de gain constitué d'une paire de transistors différentielle et d'un étage de mixage constitué de deux paires de transistors différentielles. Pour empêcher le bruit image de passer de l'étage de gain à l'étage de mixage ou pour empêcher la transmission à l'étage de gain des oscillations de l'oscillateur local de l'étage de mixage sous l'effet d'une capacité parasite, un filtre est monté entre ces étages. Dans l'une des configurations de l'invention, ce filtre est un filtre éliminateur de bande accordé de façon à bloquer la fréquence image ou la fréquence de l'oscillateur local.

(57) A conventional tree mixer has a gain stage formed of a differential pair of transistors and a mixing stage formed of two differential pairs of transistors. To prevent image noise from passing from the gain stage to the mixing stage or to prevent local oscillator frequencies from being coupled from the mixing stage to the gain stage due to parasitic capacitance an interstage filter is provided. In one configuration the filter is a notch filter tuned to block either the image frequency or the local oscillator frequency.

Abstract

A conventional tree mixer has a gain stage formed of a differential pair of transistors and a mixing stage formed of two differential pairs of transistors. To prevent image noise from passing from the gain stage to the mixing stage or to prevent local oscillator frequencies from being coupled from the mixing stage to the gain stage due to parasitic capacitance an interstage filter is provided. In one configuration the filter is a notch filter tuned to block either the image frequency or the local oscillator frequency.

WHAT WE CLAIM IS:

1. A tree mixer having a gain stage, a mixing stage and an interstage filter connected between the gain stage and the mixing stage and tuned to pass an input signal at a desired frequency from the gain stage to the mixing stage and reject one or more unwanted frequencies.

2. A tree mixer according to claim 1, wherein the filter is a notch filter tuned to block image noise.

3. A tree mixer according to claim 1, wherein the filter is a notch filter tuned to block local oscillator frequencies in the mixing stage from coupling to an input of the gain stage.

4. A tree mixer according to claim 2, wherein the notch filter is tunable.

5. A tree mixer according to claim 3, wherein the notch filter is tunable.

6. A tree mixer according to claim 2, wherein the tree mixer is adapted for receipt of differential input signals and wherein the notch filter comprises a first resonant circuit connected across an output of the gain stage and tuned to present low impedance to the image frequency and two second resonant circuits connected between the gain stage and the mixing stage and tuned to present high impedance to the image frequency.

7. A tree mixer according to claim 3, wherein the tree mixer is adapted for receipt of differential input signals and wherein the notch filter comprises a first resonant circuit connected across an output of the gain stage and tuned to present low impedance to the local oscillator frequencies and two second resonant circuits connected between the gain stage

and the mixing stage and tuned to present high impedance to the local oscillator frequencies.

8. A tree mixer according to claim 6, wherein the first resonant circuit comprises a series combination of two inductors interconnected by a capacitor and each second resonant circuit comprises a parallel combination of an inductor and capacitor.

9. A tree mixer according to claim 7, wherein the first resonant circuit comprises a series combination of two inductors interconnected by a capacitor and each second resonant circuit comprises a parallel combination of an inductor and capacitor.

10. A tree mixer according to claim 8 further comprising a varactor in series with each capacitor.

11. A tree mixer according to claim 9 further comprising a varactor in series with each capacitor.

12. A tree mixer according to claim 1, wherein the filter is a bandpass filter tuned to reject image frequencies and to block local oscillator frequencies in the mixing stage from coupling to an input of the gain stage.

13. A tree mixer according to claim 2, wherein the tree mixer is adapted for receipt of single ended input signals and wherein the notch filter comprises a resonant circuit connected between the gain stage and the mixing stage and tuned to present high impedance to the image frequency.

14. A tree mixer according to claim 3, wherein the tree mixer is adapted for receipt of single ended input signals and wherein the notch filter comprises a resonant circuit connected between the gain stage and the mixing stage and tuned to present high impedance to the local oscillator frequencies.

15. A tree mixer according to claim 13, wherein the resonant circuit comprises a parallel combination of an inductor and a capacitor.

16. A tree mixer according to claim 14, wherein the resonant circuit comprises a parallel combination of an inductor and a capacitor.

17. A tree mixer according to claim 15 further comprising a varactor in series with each capacitor.

18. A tree mixer according to claim 16 further comprising a varactor in series with each capacitor.

19. In a tree mixer comprising a gain stage having a first differential pair of transistors to which a first differential input signal is applied and a mixing stage having two second differential pairs of transistors to which a second differential input signal is applied, each second differential pair being connected to a respective one of the first differential pair whereby the first differential input signal is mixed with the second differential input signal, the improvement comprising an interstage filter connected between the gain stage and the mixing stage and tuned to pass the frequency of the first differential input signal and reject one or more unwanted frequencies.

20. A tree mixer according to claim 19, wherein the filter is a notch filter tuned to block image noise.

21. A tree mixer according to claim 19, wherein the filter is a notch filter tuned to block the second differential input signal from coupling to input electrodes of the first differential pair of transistors.

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Field of the Invention

This invention relates to mixers, and is particularly concerned with a tree mixer, which can provide linear and low-noise operation. Such mixers are specially useful in radio communications systems.

Background of the Invention

Tree mixers, also known as analog multipliers or Gilbert multipliers, have been widely used in integrated circuits for communications systems for many years. As is known for example from B. Gilbert, "A Precise Four-Quadrant Multiplier with Subnanosecond Response", IEEE Journal of Solid-State Circuits, Vol. SC-3. Pages 365-373, December 1968, such a mixer or multiplier typically comprises a first or lower differential pair of common emitter transistors to the bases of which a first differential analog input signal is supplied, and two second or upper differential pairs of transistors whose bases are supplied with a second differential analog input signal and whose collector-emitter paths conduct the currents of the lower pair of transistors to produce in their collector circuits an analog output signal which represents the product of the input signals. A single current source in the emitter circuit of the lower pair of transistors provides bias current to all six transistors. For use as a mixer in a radio communications receiver or transmitter, for example an input signal is applied to the lower pair of transistors and a local oscillator signal is applied to the two upper pairs, or upper quad, of transistors.

Degeneration resistors connected to the emitters of the lower differential pair of transistors serve to linearize the input stage to accommodate larger input signals without distorting.

Such a circuit provides advantages of good rejection of the input signals at the output, good power supply rejection, and the possibility of conversion gain.

There are three main disadvantages, however, of this conventional tree mixer.

Firstly, there is a trade-off between noise and

distortion, which limits the achievable dynamic range. Noise can be reduced, but distortion is increased, by decreasing the bias current and resistance in the emitter circuit of the lower pair of transistors. Conversely distortion can be reduced (linearity increased) by increasing these parameters, but this increases noise, especially shot noise from the upper quad of transistors, this being proportional to the bias current.

Secondly, energy and noise from the input image frequency may appear at the mixer input and mix to the output, at which point it will mask the desired signal. Image noise in the degeneration resistors and bias circuit will also mix to the output. The result is an increase in output noise and a loss in dynamic range.

Thirdly, local oscillator (LO) energy (fundamental and harmonic) may couple to the mixer input through parasitic capacitances and circuit imbalances. LO feed-through to the input is also enhanced by the wide-band coupling between lower pair and mixing transistors. This may limit the dynamic range of the mixer by overloading the mixer input. Spurious frequencies (e.g. LO harmonics, associated mixing terms) or DC offsets (e.g. leakage to the mixer input mixing with LO) may also be observed at the mixer outputs due to LO coupling to the input.

Attempts to improve the dynamic range of tree mixers have been made. For example, two identical tree mixers have been combined with quadrature phase shifting networks to suppress the energy at the image frequency. Good image rejection (e.g. greater than 50dB) can be achieved with this topology, at a cost of additional circuit complexity and power consumption (e.g. typically a factor of 2). Note that intrinsic image noise in the mixer is not suppressed.

As another example, class AB biasing schemes have been employed. These schemes reduce the DC bias in the mixer, thereby reducing shot noise in the mixing quad transistors, without degrading linearity. However, these circuits offer no image rejection capability. Two biasing schemes falling within this category are described by J. Durec et al in "Motorola's

Mosaic V Silicon Bipolar RF Building Blocks Fill Gaps in High Performance Low Power Wireless Chip Sets", Proceedings of the 4th Wireless Symposium, Santa Clara, U.S.A., pages 218-223, 1996 and by B. Gilbert in "Design Considerations for BJT Active Mixers. (course notes)" 1995.

A further example is described in U.S. Patent 5,532,637 which issued on July 2, 1996 to Khoury et al. This scheme also improves noise performance by reducing the DC current flowing in the upper quad thereby reducing the shot noise in the upper quad transistors. While this circuit maintains good linearity for small signal inputs, it ultimately reduces the maximum undistorted signal that can be obtained at the output. It also offers no image rejection capability.

None of the circuits that have been described above provide any suppression of local oscillator energy at the mixer input. Insertion of a cascode stage between the lower pair and upper quad may improve LO suppression but will cost in terms of voltage headroom, which could be a problem in low voltage circuits.

A common practice for improving overall noise performance and linearity in radio receivers is the use of an image-reject filter between the amplification and mixer stages. However, in the case where the mixer stage is a tree mixer, the image filter is usually inserted at the mixer (i.e. lower pair) input and hence does not suppress image noise contribution in the lower pair, nor does it prevent LO energy from leaking to the input.

An object of the invention is to provide a tree mixer in which one or more of the above described disadvantages is obviated or mitigated.

Summary of the Invention

The invention involves the insertion of a filter between the mixer lower pair and upper quad of a tree mixer. Ideally, the filter will pass the desired input signal to the upper quad transistors while blocking all out-of-band signal energy and noise. The theory of operation of the tree mixer with interstage filter is best understood if one considers the

tree mixer to be composed of two portions; a linear transconductance gain stage defined by the lower pair and a transimpedance mixing stage defined by the mixing quad and loads. The interstage filter will prevent/suppress undesirable signal energy and noise from entering the mixing quad.

Broadly, the invention may be summarized as a tree mixer having a gain stage, a mixing stage and an interstage filter connected between the gain stage and the mixing stage and tuned to pass an input signal at a desired frequency from the gain stage to the mixing stage and reject one or more unwanted frequencies.

The invention may result in one or more of the following advantages:

1) Improved image rejection and lower circuit noise are achievable, resulting in an improvement in dynamic range.

2) Local oscillator energy (fundamental and harmonic) may be effectively suppressed from the tree mixer input. This enhancement may improve overall dynamic range and may minimize spurious energy and offsets from appearing at the mixer output.

3) The tree mixer with interstage filter can be fully realized on a single chip using commercially-available integrated circuit process technologies.

4) The tree mixer with interstage filter as a building block can be incorporated in more complex mixer topologies.

5) The performance gains that can be achieved by the invention may result in a lower overall product cost through a relaxation in the specifications of other components in the system.

Brief Description of the Drawings

Preferred embodiments of this invention will now be described with reference to the attached drawings in which:

Figure 1 is a schematic diagraph illustrating a conventional tree mixer;

Figure 2a is a schematic diagram illustrating a tree mixer according to one embodiment of the present invention;

Figure 2b is a schematic diagram of an interstage filter used in the mixer of Figure 2a;

Figures 3a, b and c are schematic diagrams

illustrating three variants of the circuit illustrated in Figure 2;

Figure 4 is a block diagram illustrating how two mixers of the present invention may be combined;

Figures 5 through 8b are schematic diagrams illustrating further variants of the circuit illustrated in Figure 2; and

Figure 9 illustrates a single-ended input version of the mixer according to the invention.

Detailed Description of the Preferred Embodiments

Referring to Figure 1, a known tree mixer includes a differential pair of transistors 11 and 12 whose emitters are connected to a constant current source 10 via respective emitter resistors 13 and 14. The constant current source 10 is connected to a negative power supply VEE- and may be constituted simply by a resistor having a suitable value for deriving a desired current or it may be constituted by a specific semiconductor circuit. A first differential analog input signal is supplied to the bases of the transistors 11 and 12 via input terminals Vin+ and Vin- respectively. Two differential pairs of transistors 15, 16 and 17, 18 are connected in the collector circuits of the transistors 11 and 12 respectively. A second differential analog input signal is supplied to the bases of the transistors 15 and 16 via input terminals VLO+ and VLO- respectively. The transistors 15 and 16 have their emitters connected together and to the collector of the transistor 11, and have their collectors connected to differential output terminals Vout+ and Vout- respectively and via respective resistors 19 and 20 to a positive supply voltage VCC+. The second differential analog input signal is also supplied via the input terminals VLO+ and VLO- to the bases of the transistors 17 and 18 respectively, whose emitters are connected together and to the collector of the transistor 12, and whose collectors are cross-connected to the differential output terminals Vout- and Vout+ respectively.

In operation of the tree mixer of Figure 1, the current I passed by the current source 10 is divided between

the transistors 11 and 12 according to the first input signal, the degeneration resistors 13 and 14 increasing a maximum useful input voltage for the mixer and setting an effective transconductance for this input stage of about 1/(2 Re) where Re is the resistance of each of the resistors 13 and 14. Transistors 15 to 18 multiply the currents of the transistors 11 and 12 alternately by +1 and -1 at the frequency of the second signal supplied differentially to the inputs VLO+ and VLO-. In a radio communications mixer, the second signal is typically a local oscillator (LO) signal. The collector currents of the transistors 15 to 18 are converted to a differential output voltage by the collector resistors 19 and 20, with a single sideband conversion gain of $(2/\pi)(Rc/Re)$ where Rc is the resistance of each of the resistors 19 and 20.

As explained above, in a conventional tree mixer of the type illustrated in Figure 1 signal energy and noise at the image frequency can appear at the outputs of the mixer and mask the desired signal. To counteract this, the tree mixer is, according to the invention, provided with an interstage filter 24 as shown in Figure 2a. The circuit of Figure 2a is identical to that of Figure 1 except that the filter 24 is inserted between the lower pair of transistors 11 and 12 and the upper quad 15 to 18. More specifically the filter 24 is a notch filter tuned to pass a wide band of frequencies except the image frequency.

As shown in Figure 2b, the notch filter 24 comprises a first resonant circuit 25 comprising inductors 26 and 27 connected in series with a capacitor 28. This resonant circuit 25 is connected across the collectors of the lower transistor pair. Two second resonant circuits 30 and 31 are also provided. One second resonant circuit 30 is connected between the collector of transistor 11 of the lower pair and the emitters of transistors 15 and 16 of the upper quad and the other second resonant circuit 31 is connected between the collector of transistor 12 and the emitters of transistors 17 and 18 of the upper quad. Each resonant circuit 30, 31 comprises an inductor 32, 32′ connected in parallel with a

capacitor 33, 33'.

The first resonant circuit 25 is tuned to present low impedance to the image frequency and the resonant circuits 30 and 31 are tuned to present a high impedance to the image frequency. In this way image rejection is achieved. Alternatively, the tuning may be designed with respect to the Lo frequency to suppress fundamental and harmonic LO frequencies at the tree mixer inputs.

Figures 3a, b and c illustrate variants of the circuit of Figure 2a in which a cascode stage 35 is provided between the filter 24 and the upper quad (Figure 3a), between the filter and the lower pair (Figure 3b) and between the upper quad and the outputs (Figure 3c). A cascode amplifier stage (i.e. cascaded common-base stage in the case of bipolar transistors) offers the following improvements in a circuit: 1) Improved isolation between circuit terminals (output to input); 2) Higher circuit bandwidth due to the absence of the Miller Effect (related to collector-base capacitive coupling); 3) Improved linearity (related to non-linear collector-base capacitance).

Figures 3a and 3b offer improved LO-input isolation. One alternative may be more suitable than the other, depending on the filter topology. Figure 3c offers better LO-output isolation, higher circuit bandwidth (especially important for up-converter applications) and higher linearity.

Referring now to Figure 4, the novel tree mixer 22 can also be used in conventional image-reject downconverters and single-sideband upconverters with an improvement in overall noise performance and image rejection. The circuitry comprises two mixers 22 both connected to an input 37. A local oscillator in-phase frequency is mixed into one of the mixers 22 and a quadrature phase shifter 38 derives a quadrature component of the LO frequency which is then mixed into the other mixer 22. The output of that mixer is phase shifted with another quadrature phase shifter 39 the output of which is summed in a summer 40 with the output of the first mixer.

Figure 5 illustrates a variant of the circuit of

Figure 2a in which the filter 24 is tunable. In this case the filter components are identical to those shown in Figure 2b except that varactors 42 are added to fixed capacitors 28, 32, 32′. This allows the filter to be tuned to different image (or LO) frequencies thereby permitting use of a single device in applications that must comply with different radio standards.

A "folded" tree mixer topology can also be realized with the use of an interstage filter. This is illustrated in Figure 6. As is known in the art, the folded topology saves voltage headroom allowing the mixer to be used in applications with lower supply voltages.

Modified tree mixers with common-base inputs may also incorporate an interstage filter. Such a variant is shown in Figure 7. As is known in the art, the common-base input stage offers a lower input impedance than the common-emitter input stage. The lower impedance may be desirable for improved power matching between the input source and the input stage. A drawback to the common-base input stage is a lack of current gain (vs. the common-emitter stage which has current gain).

The disclosed invention may be applied to a variety of device and process technologies (e.g., NPN BJT, PNP BJT, N-FET, P-FET, CMOS, BiCMOS) as well. Examples of PNP and NMOS variants are illustrated in Figures 8a and 8b.

Figure 9 illustrates a version of the mixer according to the invention in which, instead of a differential input signal, a single-ended input signal Vin is applied. Thus, as is known in the art, there is a single transistor 11 in the gain stage and a single pair of transistors 15, 16 in the mixing stage. The interstage filter 24 illustrated comprises an inductor 32 in parallel with a capacitor 33 serving as a series notch filter, and inductor 26 and a capacitor 28 connected in series to ground serving as a shunt notch filter.

The type of interstage filter described in the illustrated embodiments of the invention is a notch filter. Such a filter was chosen as a practical, effective topology to couple the high impedance collectors of the lower transistor pair to the low impedance emitters of the upper quad

transistors. The filter is bilateral (operates in both directions) which means that if tuned properly, it can reject LO leakage from the upper quad to the lower pair. A notch filter has the advantage that it can be achieved while providing direct coupling from input to output. This is essential where DC bias to the mixing quad transistors is derived from DC bias in the lower pair transistors as is the case with conventional mixers. For low voltage circuits where separate biasing is established for the upper quad and the lower pair, direct coupling should be avoided.

A disadvantage of the notch filter is that it rejects only one unwanted frequency and cannot reject both the image and LO frequencies at the same time. A bandpass filter would be better such that all or most unwanted frequencies could be rejected but it may be difficult to design such a bandpass filter that also provides direct coupling. However, it is considered that any interstage filter which passes the desired frequencies and rejects some or all of the undesired frequencies falls within the scope of the present invention.

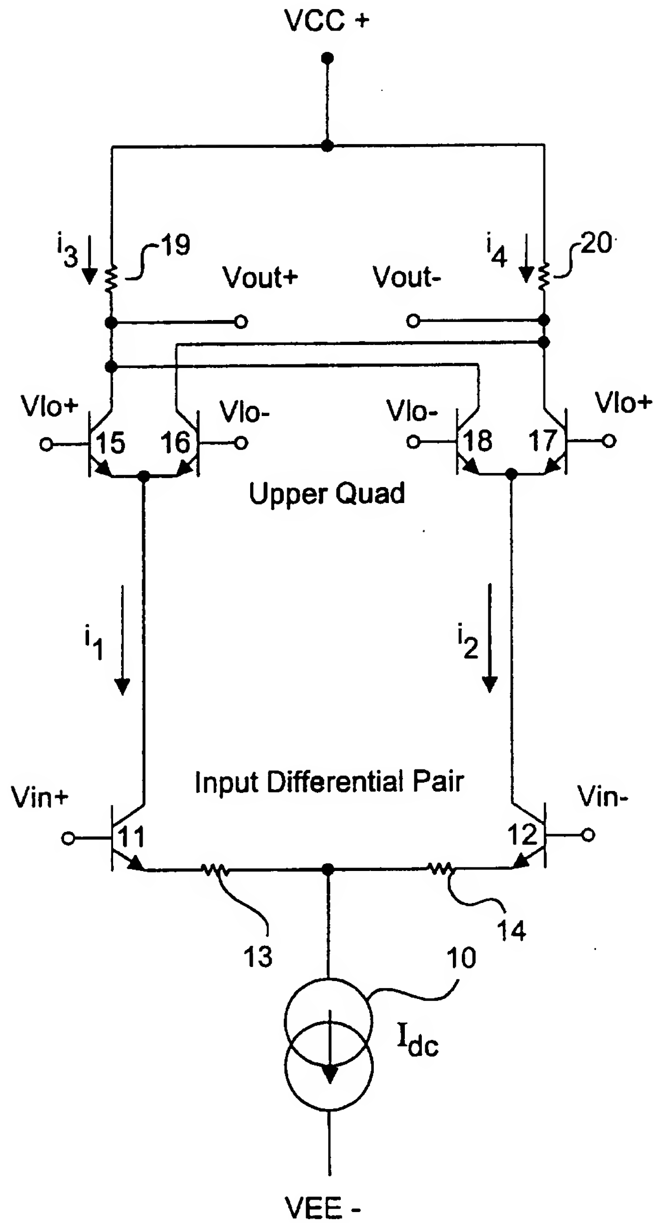

FIG. 1
PRIOR ART

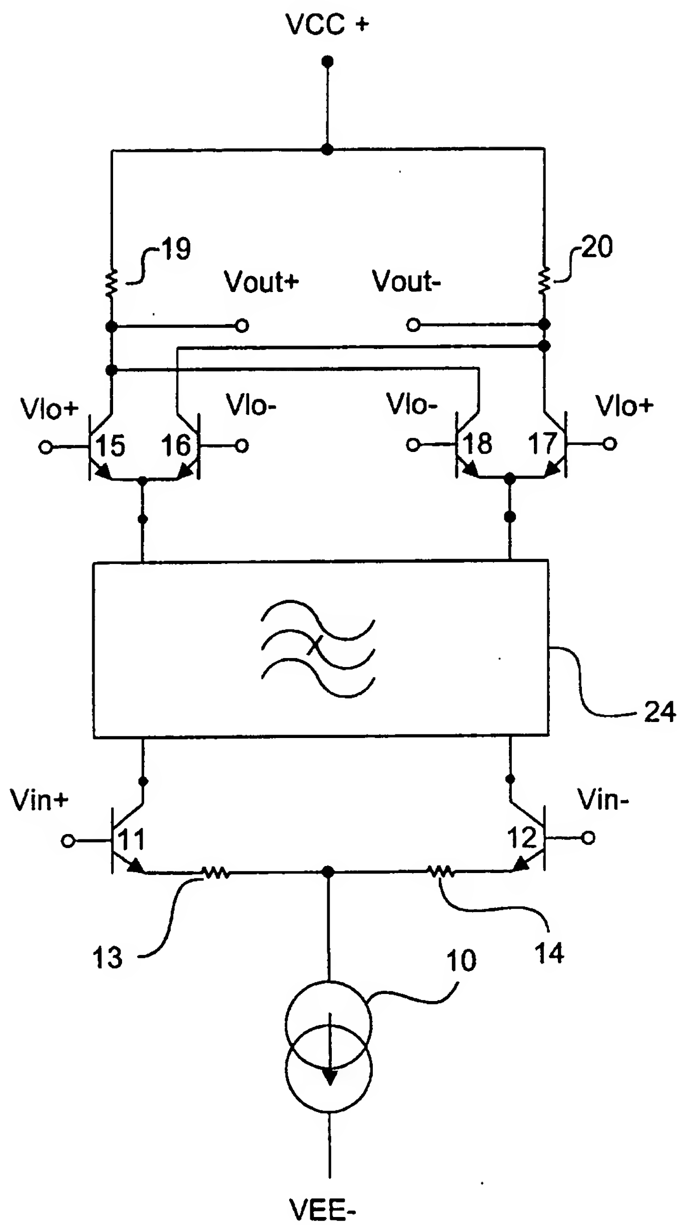
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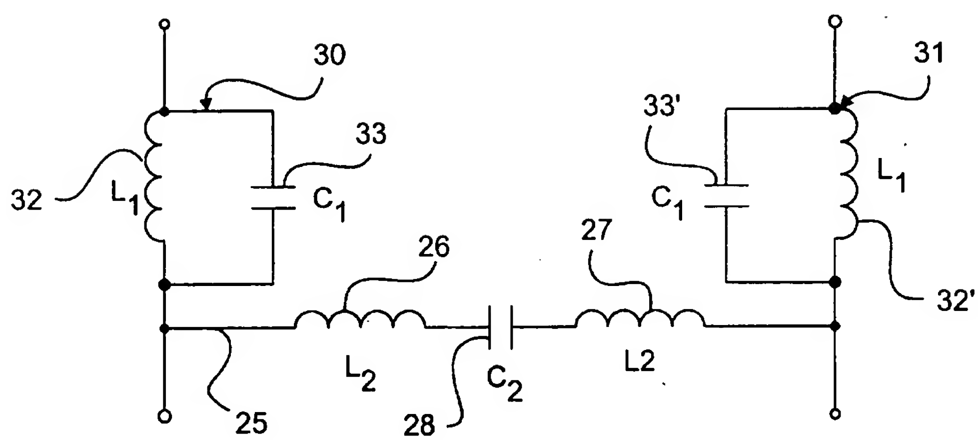
FIG. 2a

FIG. 2b



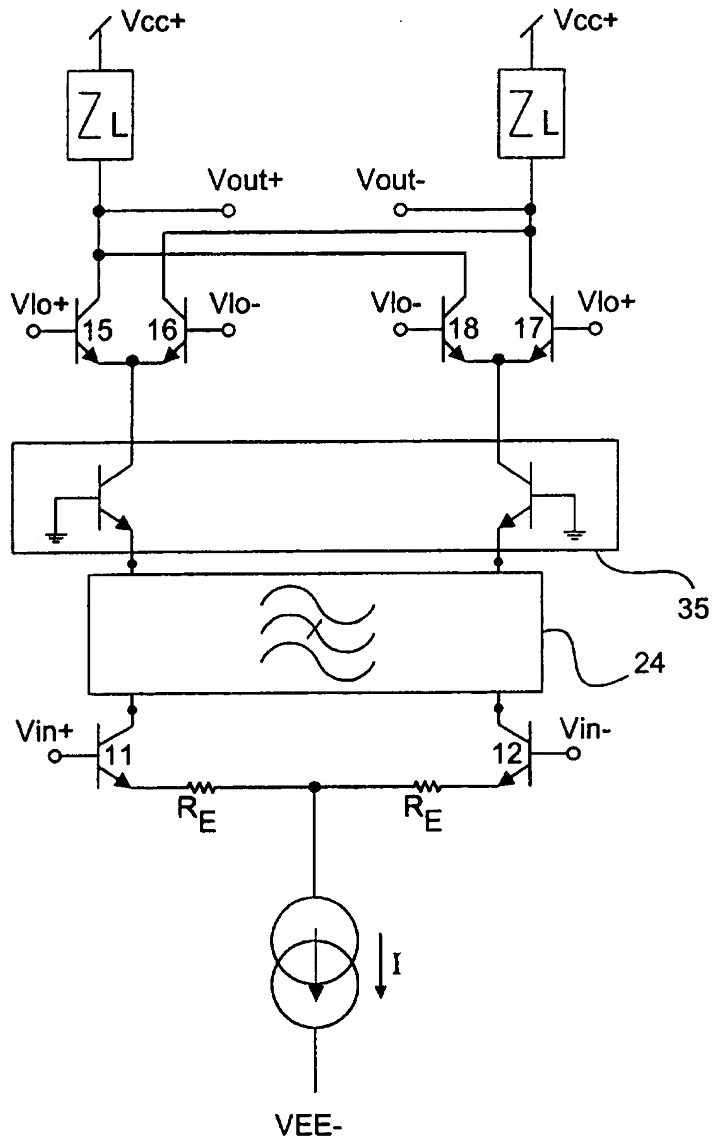

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FIG. 3a

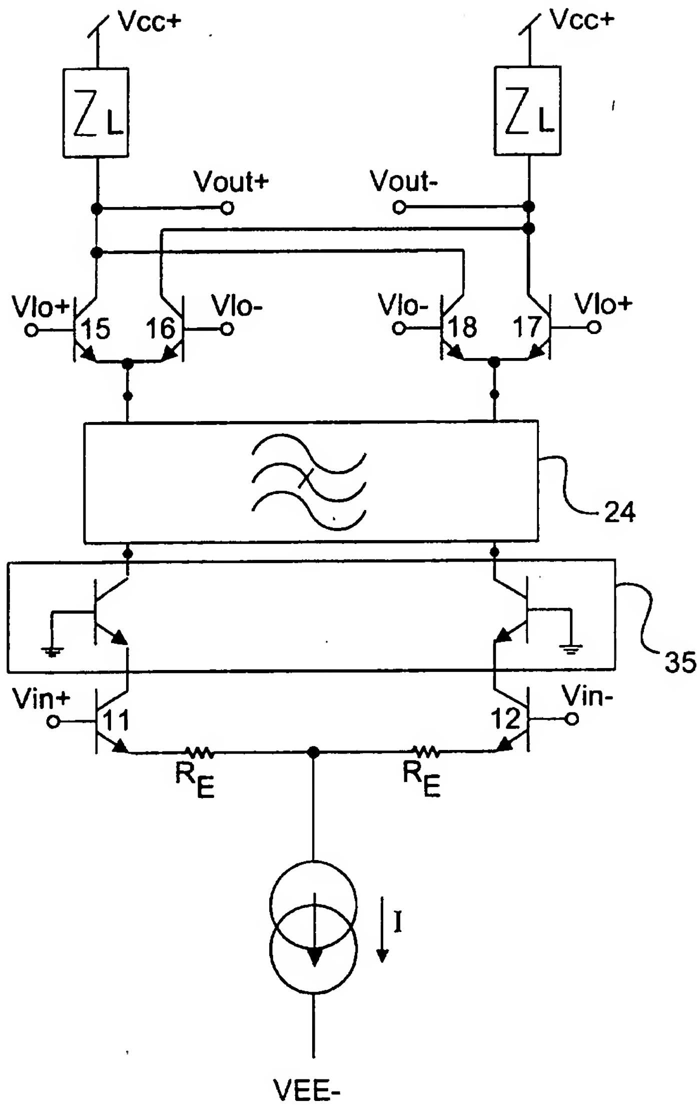
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FIG. 3b

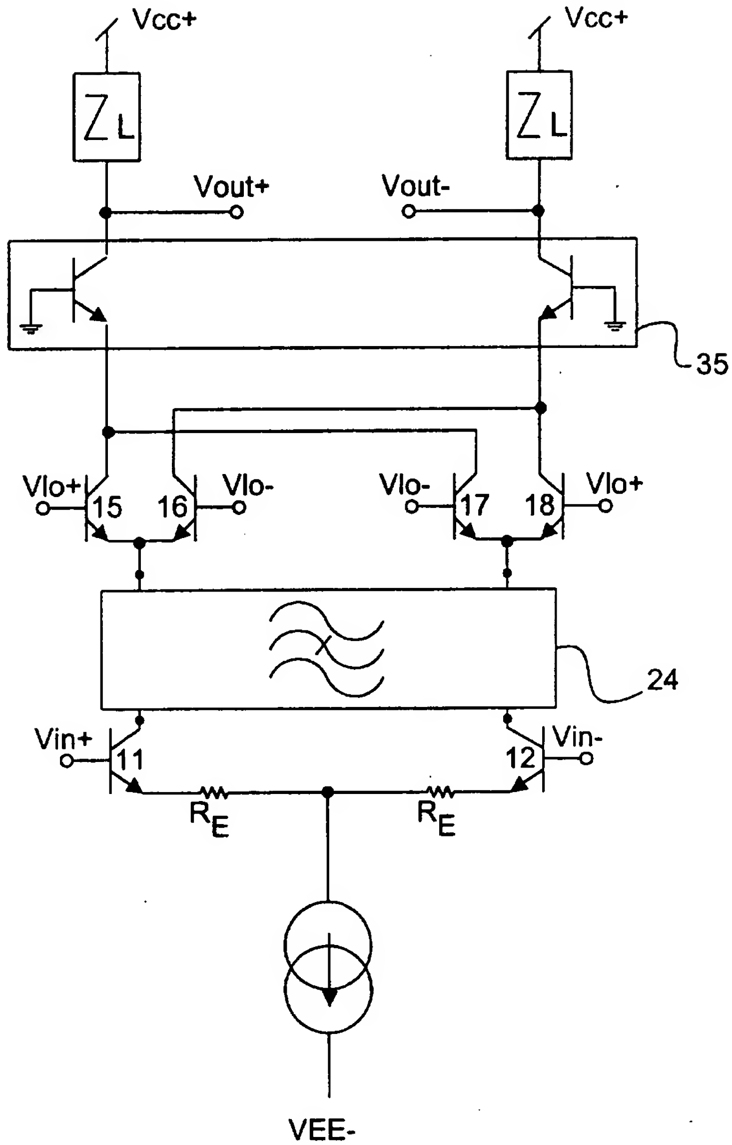
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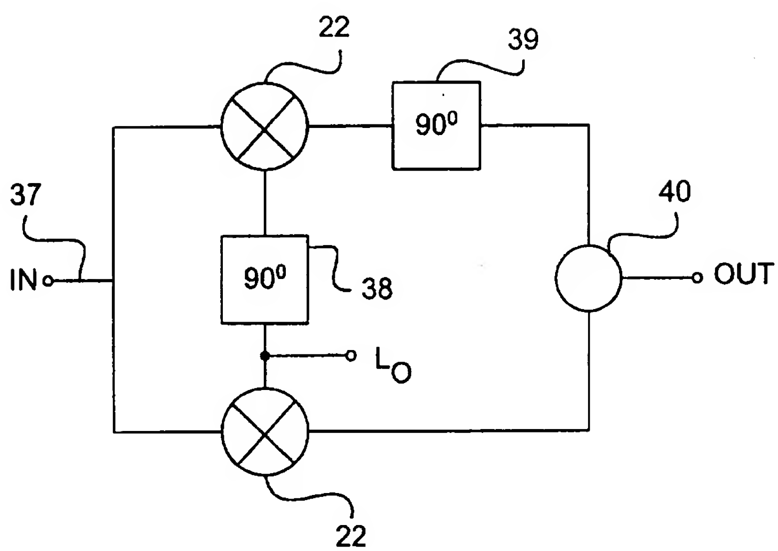
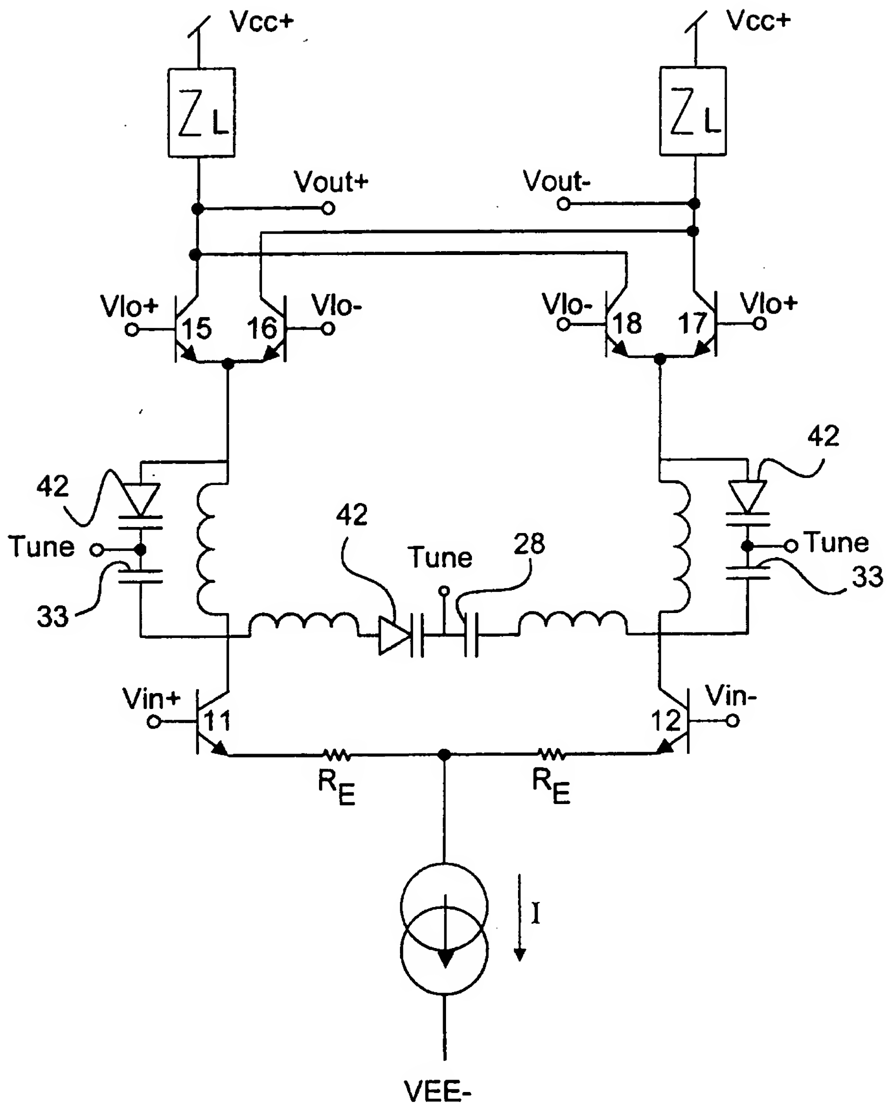
FIG. 3c

FIG. 4

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28
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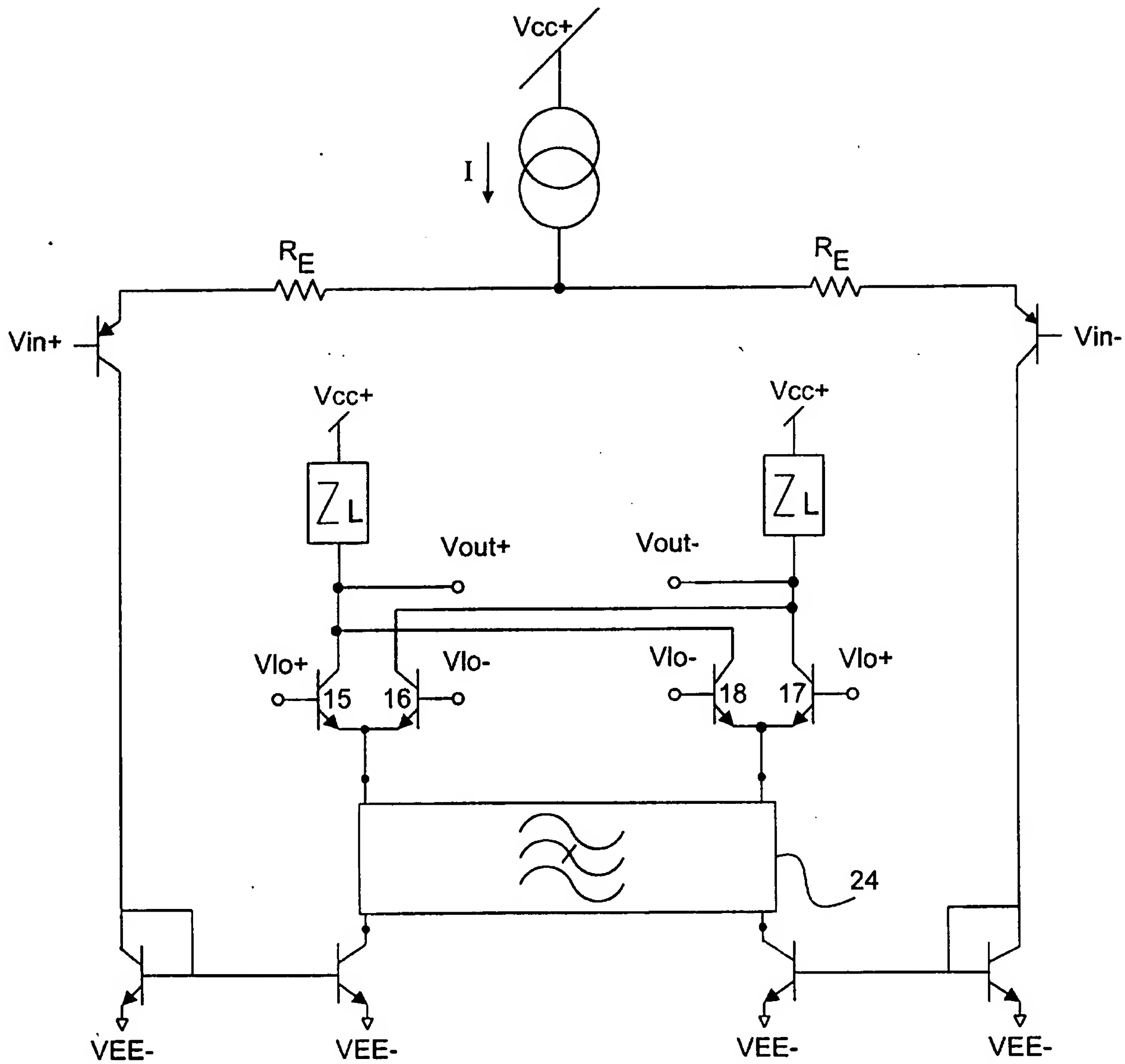
FIG. 5



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Z_L
Vout+
Vout-
Vlo+
Vlo-
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VEE-
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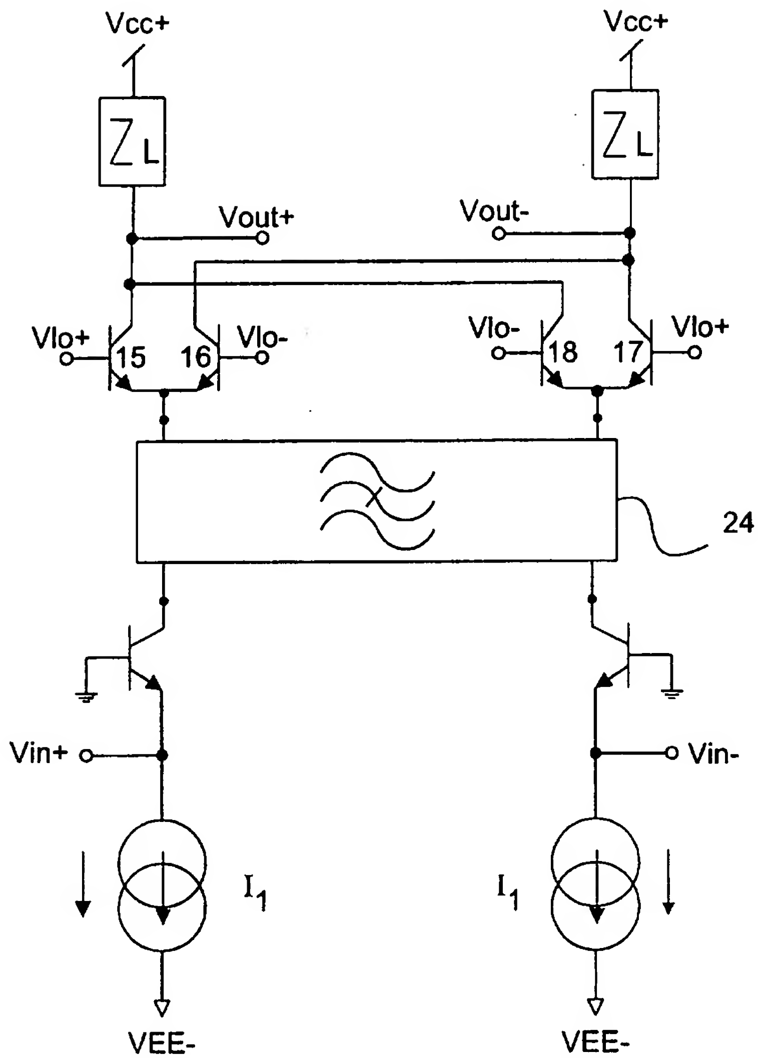
FIG. 6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I1
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VEE-
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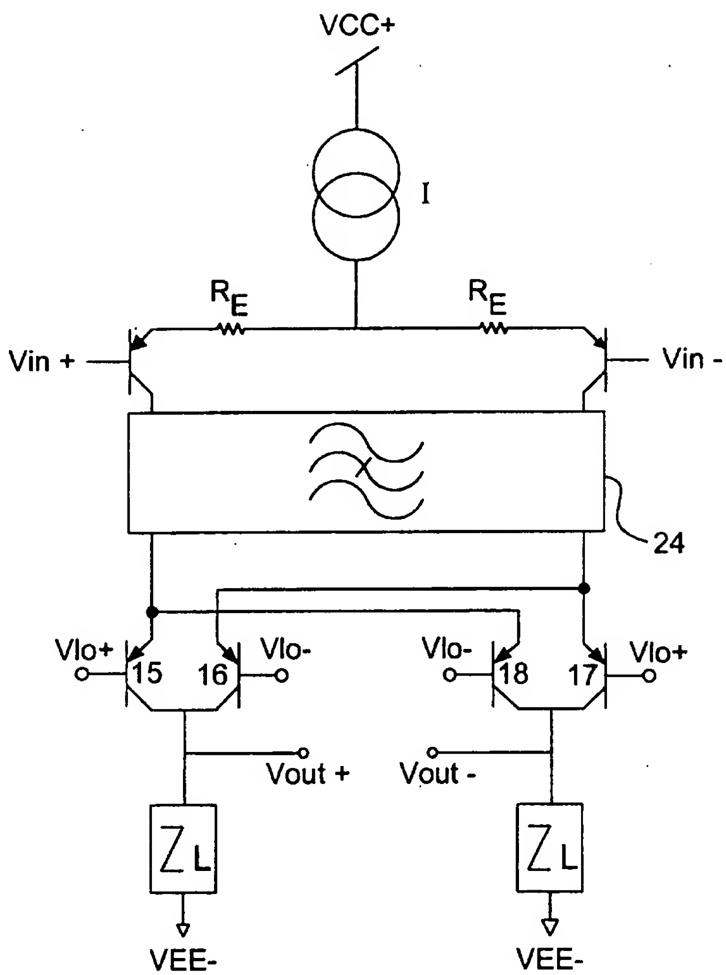
FIG. 7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Z_L
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VEE-
VEE-

FIG. 8a

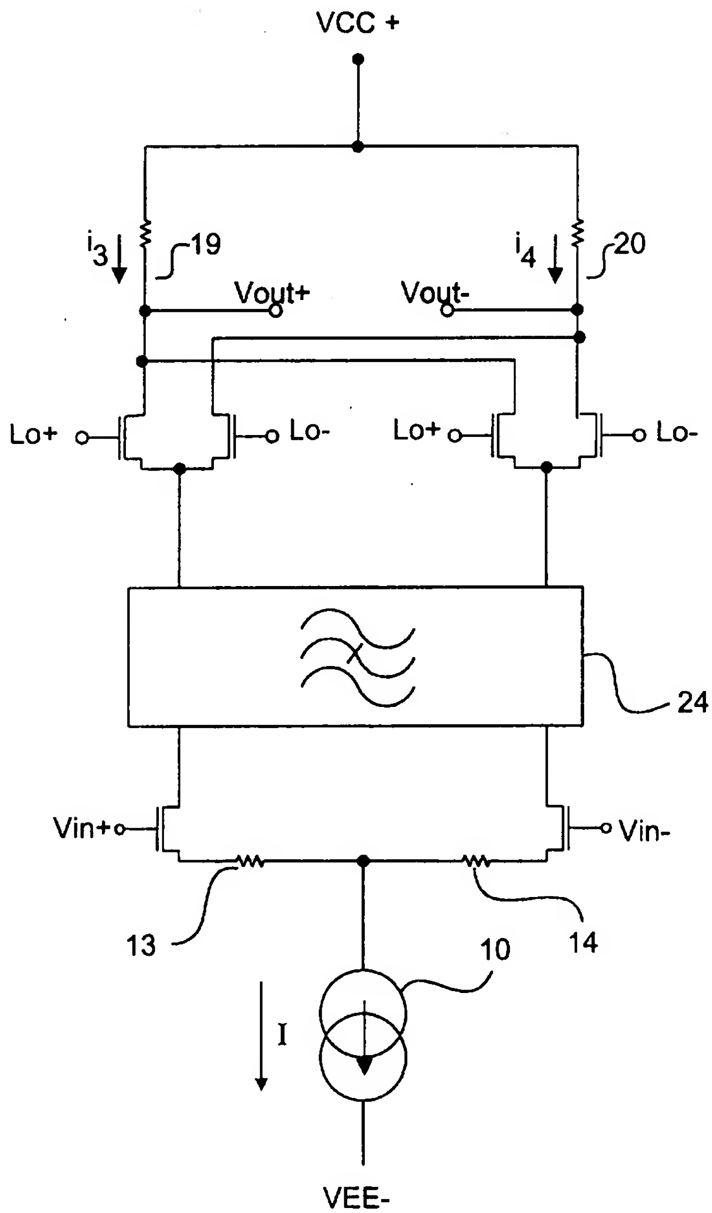


FIG. 8b

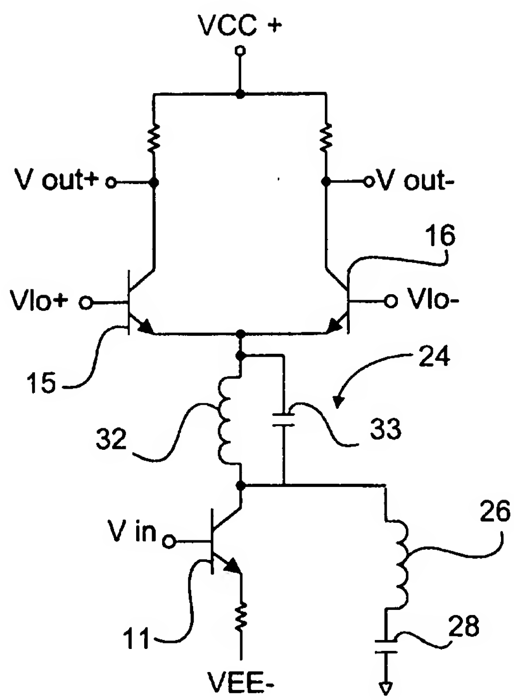
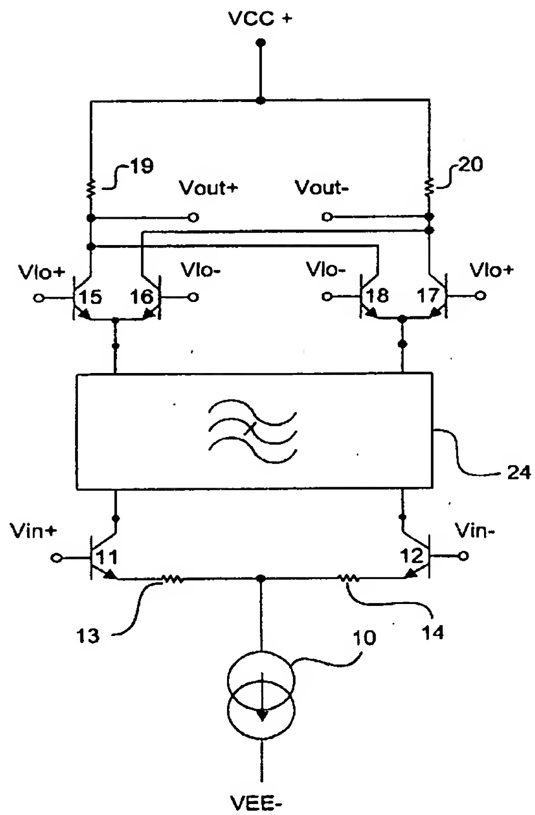


FIG. 9



VCC +
19
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Vlo-
Vlo-
Vlo+
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Vin-
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12
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VEE-